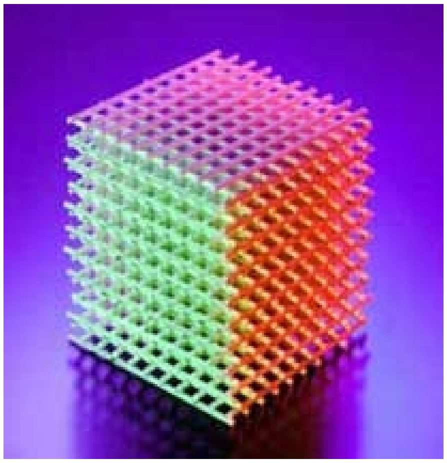
# Energy@23 Award Nomination
# Photonic Bandgap Structures (PBG) - 1990

## ABSTRACT:

**This nomination recognizes advances in photonic bandgap (PBG) structures, periodic dielectric structures that forbid the propagation of electromagnetic waves in a certain frequency range. Photonic "crystals" have a variety of possible applications: in lasers, antennas, millimeter wave devices, efficient solar cells and photocatalytic processes. They also give rise to interesting new physics in cavity electrodynamics, localization, disorder and photon-number-state squeezing. DOE laboratory scientists are involved in several projects of both theoretical and experimental natures. This research has applications that include higher efficiency antennas at microwave and millimeter wave frequencies; high Q-frequency selective filters; receivers; PBG structures at near-infrared and optical wavelengths; and PBGs for photocatalysis.**



## PROGRAM DESCRIPTION:

More than a decade ago, scientists around the world began toying with the idea that it was possible to build a light-containing artificial crystal. That dream became a reality in 1990 when scientists at DOE's lab were the first to demonstrate that building such a crystal was, in fact, possible.

DOE remains at the forefront of both theoretical and experimental PBG research, developing methods to make crystals that bend far more light in far less space than current technology. This is leading to applications in data transmission and in more compact and efficient sensors and antennas. This PBG research is important because of its broad capabilities for making electronics more energy efficient and reliable.

This groundbreaking discovery has paved the way for researchers around the world to fabricate increasingly smaller crystals, known as photonic bandgap (PBG) structures that trap as much as 95% of certain frequencies of light sent into them. This is a vast improvement compared to the 30% trapped by the conventional waveguides. Additionally, the small PBG structures can bend the light in a fraction of the space needed by conventional waveguides.

During the past ten years, this DOE laboratory has developed a novel diamond-lattice structure for PBG crystals that has been used to fabricate devices that operate at microwave and millimeter wave frequencies. The smallest PBG crystal ever fabricated, which operates at wavelengths between 1.35 and 1.95 microns, also used the Ames Lab layered lattice design.

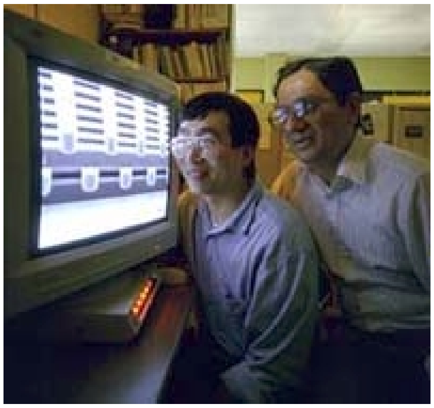
## IMPROVING THE QUALITY OF LIFE:

Photonic bandgap devices allow control of electromagnetic radiation that will enable scientists to develop increasingly smaller, more precise lasers for medical use.

Photonic crystals will also play a vital role in optical communications, such as the Internet. With the increasing growth of information technology and the Internet, optical fibers operating at 1.5-micron wavelengths are being employed for high-bandwidth communications. Optic-fiber backbones are perhaps the only viable choice for integrating the large amounts of data and video in the evolving Internet marketplace. Manipulating, switching, and multiplexing optic-fiber channels is an area where photonic crystals are expected to have an important role.

Photonic crystals can be tailored to have no losses with certain wavelength bands, which permits building high-efficiency optical components with novel photonic crystal-based designs.

All-optical computing will lead to an improvement of computing power by several magnitudes over existing technology. Optical computing involves the use of photons rather than the electrons now used by desktop computers to pass information. However, as more circuits are included on new chips, they become more and more difficult to cool. Photons are faster and cooler than electrons, but researchers have been unable to bend useful photonic frequencies through the millions of turns on a single chip without losing much of the information. Photonic crystal-based devices could solve this problem.



## COST SAVINGS:

By enabling us to control electromagnetic radiation, photonic bandgap devices are expected to reduce energy loss and increase efficiency in a variety of technologies, such as solar cells, sensing devices, and antennas. Photonic bandgap devices block energy loss in lasers, increasing their efficiency and reducing noise and interference in signals from the lasers. Because little light is lost in the light-trapping process of the PBG structures, a new type of microlaser requiring little start-up energy is theoretically achievable. (Most conventional lasers require large jolts of energy to begin operating because so much light is lost in the start-up process.)

## OTHER NOTEWORTHY BENEFITS:

Researchers at DOE's lab were the first to prove the existence of photonic bandgap crystals. This has spawned a steadily increasing research and knowledge base on photonic crystals throughout the world.

In 1990, a diamond structure for a three-dimensional PBG crystal was devised. This was fabricated by Eli Yablonovitch at Bellcore Labs and contained a bandgap in the microwave region of the electromagnetic spectrum.

Researchers improved the design for the structure by using a layered lattice in which alumina rods were stacked in alternating layers. This design was patented in 1992, and several structures were built that operated in the microwave and millimeter wave regions.

As researchers continued searching for ways to make the structures smaller for the applications at optical or near-infrared wavelengths, they began collaborating with another DOE lab which used Ames Lab's design in 1998 to fabricate a three-dimensional diamond structure with a bandgap of about 12 microns, the region near where carbon-dioxide lasers operate. Later that year, the second group of researchers fabricated an even smaller version of our layered-lattice design, producing the smallest crystal ever fabricated with a complete three-dimensional photonic bandgap. It is effective at wavelengths between 1.35 and 1.95 microns, a significant achievement because the wavelength used for the transmission of telecommunications by optical fibers is 1.5 microns.

The ability to control and manipulate light through the use of photonic bandgap devices has unlimited applications in the world of electronics.

The research has resulted in greater knowledge about the behavior and properties of atoms, especially their abilities to promote or accelerate chemical reactions, which may have significant impact in the medical and pharmaceutical industries.

***Submitted by: Ames Laboratory***